MS. B, 3--three slight sketches of plans in connexion with the preceding ones.

Pl. XCIX, No.1 (MS. Tr. 15) contains several small sketches of sections and exterior views of the Dome; some of them show buttress-walls shaped as inverted arches. Respecting these Leonardo notes:

758.

L'arco rivescio e migliore per fare spalla che l'ordinario, perche il rovescio trova sotto se muro resistete alla sua debolezza, e l'ordinario no trova nel suo debole se non aria

The inverted arch is better for giving a shoulder than the ordinary one, because the former finds below it a wall resisting its weakness, whilst the latter finds in its weak part nothing but air.

[Footnote: Three slight sketches of sections on the same leaf--above those reproduced here--are more closely connected with the large drawing in the centre of Pl. C, No. 4 (M.S, Tr. 41) which shows a section of a very elevated dome, with double vaults, connected by ribs and buttresses ingeniously disposed, so as to bring the weight of the lantern to bear on the base of the dome.

A sketch underneath it shows a round pillar on which is indicated which part of its summit is to bear the weight: "il pilastro sara charicho in . a . b." (The column will bear the weight at a b.) Another note is above on the right side: Larcho regiera tanto sotto asse chome di sopra se (The arch supports as much below it [i. e. a hanging weight] as above it).

Pl. C, No. 1 (C. A. 303a). Larger sketch of half section of the Dome, with a very complicated system of arches, and a double vault. Each stone is shaped so as to be knit or dovetailed to its neighbours. Thus the inside of the Dome cannot be seen from below.

MS. C. A. 303b. A repetition of the preceding sketch with very slight modifications.]

[Figs. 1. and Fig. 2. two sketeches of the dome]

MS. Tr. 9 (see Fig. 1 and 2). Section of the Dome with reverted buttresses between the windows, above which iron anchors or chains seem to be intended. Below is the sketch of the outside.

PI. XCIX, No. 3 (C. A., 262a) four sketches of the exterior of the Dome.

C. A. 12. Section, showing the points of rupture of a gothic vault, in evident connection with the sketches described above.

It deserves to be noticed how easily and apparently without effort, Leonardo manages to combine gothic details and structure with the more modern shape of the Dome.

The following notes are on the same leaf, oni cosa poderosa, and oni cosa poderosa desidera de(scendere); farther below, several multiplications most likely intended to calculate the weight of some parts of the Dome, thus 16 x 47 = 720; 720 x 800 = 176000, next to which is written: peso del pilastro di 9 teste (weight of the pillar 9 diameters high).

Below: 176000 x 8 = 1408000; and below:

Semjlio e se ce 80 (?) il peso del tiburio (six millions six hundred (?) 80 the weight of the Dome).

Bossi hazarded the theory that Leonardo might have been the architect who built the church of Sta. Maria delle Grazie, but there is no evidence to support this, either in documents or in the materials supplied by Leonardos manuscripts and drawings. The sketch given at the side shows the arrangement of the second and third socle on the apses of the choir of that church; and it is remarkable that those sketches, in MS. S. K. M. II2, 2a and Ib, occur with the passage given in Volume I as No. 665 and 666 referring to the composition of the Last Supper in the Refectory of that church.]

F. The Project for lifting up the Battistero of Florence and setting it on a basement.

Among the very few details Vasari gives as to the architectural studies of Leonardo, we read: "And among these models and designs there was one by way of which he showed several times to many ingenious citizens who then governed Florence, his readiness to lift up without ruining it, the church of San Giovanni in Florence (the Battistero, opposite the Duomo) in order to place under it the missing basement with steps; he supported his assertions with reasons so persuasive, that while he spoke the undertaking seemed feasable, although every one of his hearers, when he had departed, could see by himself the impossibility of so vast an undertaking."

[Footnote: This latter statement of Vasari's must be considered to be exaggerated. I may refer here to some data given by LIBRI, Histoire des sciences mathematiques en Italie (II, 216, 217): "On a cru dans ces derniers temps faire un miracle en mecanique en effectuant ce transport, et cependant des l'annee 1455, Gaspard Nadi et Aristote de Fioravantio avaient transporte, a une distance considerable, la tour de la Magione de Bologne, avec ses fondements, qui avait presque quatre-vingts pieds de haut. Le continuateur de la chronique de Pugliola dit que le trajet fut de 35 pieds et que durant le transport auquel le chroniqueur affirme avoir assiste, il arriva un accident grave qui fit pencher de trois pieds la tour pendant qu'elle etait suspendue, mais que cet accident fut promptement repare (Muratori, Scriptores rer. ital. Tom. XVIII, col. 717, 718). Alidosi a rapporte une note ou Nadi rend compte de ce transport avec une rare simplicite. D'apres cette note, on voit que les operations de ce genre n'etaient pas nouvelles. Celle-ci ne couta que 150 livres (monnaie d'alors) y compris le cadeau que le Legat fit aux deux mecaniciens. Dans la meme annee, Aristote redressa le clocher de Cento, qui penchait de plus de cinq pieds (Alidosi, instruttione p. 188-- Muratori, Scriptores rer. ital., tom. XXIII, col. 888.--Bossii, chronica Mediol., 1492, in-fol. ad ann. 1455). On ne concoit pas comment les historiens des beaux-arts ont pu negliger de tels hommes." J. P. R.]

In the MS. C. A. fol. 293, there are two sketches which possibly might have a bearing on this bold enterprise. We find there a plan of a circular or polygonal edifice surrounded by semicircular arches in an oblique position. These may be taken for the foundation of the steps and of the new platform. In the perspective elevation the same edifice, forming a polygon, is shown as lifted up and resting on a circle of inverted arches which rest on an other circle of arches in the ordinary position, but so placed that the inverted arches above rest on the spandrels of the lower range.

What seems to confirm the supposition that the lifting up of a building is here in question, is the indication of engines for winding up, such as jacks, and a rack and wheel. As the lifting apparatus represented on this sheet does not seem particularly applicable to an undertaking of such magnitude, we may consider it to be a first sketch or scheme for the engines to be used.

G. Description of an unknown Temple.

759.

Twelve flights of steps led up to the great temple, which was eight hundred braccia in circumference and built on an octagonal plan. At the eight corners were eight large plinths, one braccia and a half high, and three wide, and six long at the bottom, with an angle in the middle; on these were eight great pillars, standing on the plinths as a foundation, and twenty four braccia high. And on the top of these were eight capitals three braccia long and six wide, above which were the architrave frieze and cornice, four braccia and a half high, and this was carried on in a straight line from one pillar to the next and so, continuing for eight hundred braccia, surrounded the whole temple, from pillar to pillar. To support this entablature there were ten large columns of the same height as the pillars, three braccia thick above their bases which were one braccia and a half high.

The ascent to this temple was by twelve flights of steps, and the temple was on the twelfth, of an octagonal form, and at each angle rose a large pillar; and between the pillars were placed ten columns of the same height as the pillars, rising at once from the pavement to a height of twenty eight braccia and a half; and at this height the architrave, frieze and cornice were placed which surrounded the temple having a length of eight hundred braccia. At the same height, and within the temple at the same level, and all round the centre of the temple at a distance of 24 braccia farther in, are pillars corresponding to the eight pillars in the angles, and columns corresponding to those placed in the outer spaces. These rise to the same height as the former ones, and over these the continuous architrave returns towards the outer row of pillars and columns.

[Footnote: Either this description is incomplete, or, as seems to me highly probable, it refers to some ruin. The enormous dimensions forbid our supposing this to be any temple in Italy or Greece. Syria was the native land of colossal octagonal buildings, in the early centuries A. D. The Temple of Baalbek, and others are even larger than that here described. J. P. R.]

V. Palace architecture.

But a small number of Leonardo's drawings refer to the architecture of palaces, and our knowledge is small as to what style Leonardo might have adopted for such buildings.

Pl. CII No. 1 (W. XVIII). A small portion of a facade of a palace in two stories, somewhat resembling Alberti's Palazzo Rucellai.--Compare with this Bramante's painted front of the Casa

Silvestri, and a painting by Montorfano in San Pietro in Gessate at Milan, third chapel on the left hand side and also with Bramante's palaces at Rome. The pilasters with arabesques, the rustica between them, and the figures over the window may be painted or in sgraffito. The original is drawn in red chalk.

Pl. LXXXI No. 1 (MS. Tr. 42). Sketch of a palace with battlements and decorations, most likely graffiti; the details remind us of those in the Castello at Vigevano. [Footnote 1: Count GIULIO PORRO, in his valuable contribution to the Archivio Storico Lombardo, Anno VIII, Fasc. IV (31 Dec. 1881): Leonardo da Vinci, Libro di Annotazioni e Memorie, refers to this in the following note: "Alla pag. 41 vi e uno schizzo di volta ed accanto scrisse: 'il pilastro sara charicho in su 6' e potrebbe darsi che si riferisse alla cupola della chiesa delle Grazie tanto piu che a pag. 42 vi e un disegno che rassomiglia assai al basamento che oggi si vede nella parte esterna del coro di quella chiesa." This may however be doubted. The drawing, here referred to, on page 41 of the same manuscript, is reproduced on Pl. C No. 4 and described on page 61 as being a study for the cupola of the Duomo of Milan. J. P. R.]

MS. Mz. 0", contains a design for a palace or house with a loggia in the middle of the first story, over which rises an attic with a Pediment reproduced on page 67. The details drawn close by on the left seem to indicate an arrangement of coupled columns against the wall of a first story.

Pl. LXXXV No. 14 (MS. S. K. M. Ill 79a) contains a very slight sketch in red chalk, which most probably is intended to represent the facade of a palace. Inside is the short note 7 he 7 (7 and 7).

MS. J2 8a (see pages 68 Fig. 1 and 2) contains a view of an unknown palace. Its plan is indicated at the side.

In MS. Br. M. 126a(see Fig. 3 on page 68) there is a sketch of a house, on which Leonardo notes; casa con tre terrazi (house with three terraces).

Pl. CX, No. 4 (MS. L. 36b) represents the front of a fortified building drawn at Cesena in 1502 (see No. 1040).

Here we may also mention the singular building in the allegorical composition represented on Pl. LVIII in Vol. I. In front of it appears the head of a sphinx or of a dragon which seems to be carrying the palace away.

The following texts refer to the construction of palaces and other buildings destined for private use:

760.

In the courtyard the walls must be half the height of its width, that is if the court be 40 braccia, the house must be 20 high as regards the walls of the said courtyard; and this courtyard must be half as wide as the whole front.

[Footnote: See Pl. CI, no. 1, and compare the dimensions here given, with No. 748 lines 26-29; and the drawing belonging to it Pl. LXXXI, no. 2.]

On the dispositions of a stable.

761.

FOR MAKING A CLEAN STABLE.

The manner in which one must arrange a stable. You must first divide its width in 3 parts, its depth matters not; and let these 3 divisions be equal and 6 braccia broad for each part and 10 high, and the middle part shall be for the use of the stablemasters; the 2 side ones for the horses, each of which must be 6 braccia in width and 6 in length, and be half a braccio higher at the head than behind. Let the manger be at 2 braccia from the ground, to the bottom of the rack, 3 braccia, and the top of it 4 braccia. Now, in order to attain to what I promise, that is to make this place, contrary to the general custom, clean and neat: as to the upper part of the stable, i. e. where the hay is, that part must have at its outer end a window 6 braccia high and 6 broad, through which by simple means the hay is brought up to the loft, as is shown by the machine E; and let this be erected in a place 6 braccia wide, and as long as the stable, as seen at k p. The other two parts, which are on either side of this, are again divided; those nearest to the hay-loft are 4 braccia, p s, and only for the use and circulation of the servants belonging to the stable; the other two which reach to the outer walls are 2 braccia, as seen at s k, and these are made for the purpose of giving hay to the mangers, by means of funnels, narrow at the top and wide over the manger, in order that the hay should not choke them. They must be well plastered and clean and are represented at 4 f s. As to the giving the horses water, the troughs must be of stone and above them [cisterns of] water. The mangers may be opened as boxes are uncovered by raising the lids. [Footnote: See Pl. LXXVIII, No.1.]

Decorations for feasts.

762.

THE WAY TO CONSTRUCT A FRAME-WORK FOR DECORATING BUILDINGS.

The way in which the poles ought to be placed for tying bunches of juniper on to them. These poles must lie close to the framework of the vaulting and tie the bunches on with osier withes, so as to clip them even afterwards with shears.

Let the distance from one circle to another be half a braccia; and the juniper [sprigs] must lie top downwards, beginning from below.

Round this column tie four poles to which willows about as thick as a finger must be nailed and then begin from the bottom and work upwards with bunches of juniper sprigs, the tops downwards, that is upside down. [Footnote: See Pl. CII, No. 3. The words here given as the title line, lines 1--4, are the last in the original MS.--Lines 5--16 are written under fig. 4.]

763.

The water should be allowed to fall from the whole circle a b. [Footnote: Other drawings of fountains are given on Pl. CI (W. XX); the original is a pen and ink drawing on blue paper; on Pl. CIII (MS. B.) and Pl. LXXXII.]

VI. Studies of architectural details.

Several of Leonardo's drawings of architectural details prove that, like other great masters of that period, he had devoted his attention to the study of the proportion of such details. As every organic being in nature has its law of construction and growth, these masters endeavoured, each in his way, to discover and prove a law of proportion in architecture. The following notes in Leonardo's manuscripts refer to this subject.

MS. S. K. M. Ill, 47b (see Fig. 1). A diagram, indicating the rules as given by Vitruvius and by Leon Battista Alberti for the proportions of the Attic base of a column.

MS. S. K. M. Ill 55a (see Fig. 2). Diagram showing the same rules.

764.

B toro superiore . . . . . toro superiore
2B nestroli . . . . . . astragali quadre
3B orbiculo . . . . troclea
4B nestroli . . . . . . astragali quadre
5B toro iferiore . . . . . . toro iferiore
6B latastro . . . . plintho

[Footnote: No explanation can be offered of the meaning of the letter B, which precedes each name. It may be meant for basa (base). Perhaps it refers to some author on architecture or an architect (Bramante?) who employed the designations, thus marked for the mouldings. 3. troclea. Philander: Trochlea sive trochalia aut rechanum. 6. Laterculus or latastrum is the Latin name for Plinthus (pi lambda Xiv) but Vitruvius adopted this Greek name and "latastro" seems to have been little in use. It is to be found besides the text given above, as far as I am aware, only two drawings of the Uffizi Collection, where in one instance, it indicates the abacus of a Doric capital.]

765.

STEPS OF URRBINO.

The plinth must be as broad as the thickness of the wall against which the plinth is built. [Footnote: See Pl. CX No. 3. The hasty sketch on the right hand side illustrates the unsatisfactory effect produced when the plinth is narrower than the wall.]

766.

The ancient architects ...... beginning with the Egyptians (?) who, as Diodorus Siculus writes, were the first to build and construct large cities and castles, public and private buildings of fine form, large and well proportioned .....

The column, which has its thickness at the third part .... The one which would be thinnest in the middle, would break ...; the one which is of equal thickness and of equal strength, is better for the edifice. The second best as to the usefulness will be the one whose greatest thickness is where it joins with the base.

[Footnote: See Pl. CIII, No. 3, where the sketches belonging to lines 10--16 are reproduced, but reversed. The sketch of columns, here reproduced by a wood cut, stands in the original close to lines 5--8.]

The capital must be formed in this way. Divide its thickness at the top into 8; at the foot make it 5/7, and let it be 5/7 high and you will have a square; afterwards divide the height into 8 parts as you did for the column, and then take 1/8 for the echinus and another eighth for the thickness of the abacus on the top of the capital. The horns of the abacus of the capital have to project beyond the greatest width of the bell 2/7, i. e. sevenths of the top of the bell, so 1/7 falls to the projection of each horn. The truncated part of the horns must be as broad as it is high. I leave the rest, that is the ornaments, to the taste of the sculptors. But to return to the columns and in order to prove the reason of their strength or weakness according to their shape, I say that when the lines starting from the summit of the column and ending at its base and their direction and length ..., their distance apart or width may be equal; I say that this column ...

767.

The cylinder of a body columnar in shape and its two opposite ends are two circles enclosed between parallel lines, and through the centre of the cylinder is a straight line, ending at the centre of these circles, and called by the ancients the axis.

[Footnote: Leonardo wrote these lines on the margin of a page of the Trattato di Francesco di Giorgio, where there are several drawings of columns, as well as a head drawn in profile inside an outline sketch of a capital.]

768.

a b is 1/3 of n m; m o is 1/6 of r o. The ovolo projects 1/6
of r o; s 7 1/5 of r o, a b is divided into 9 1/2; the
abacus is 3/9 the ovolo 4/9, the bead-moulding and the fillet 2/9
and 1/2.

[Footnote: See Pl. LXXXV, No. 16. In the original the drawing and writing are both in red chalk.]

Pl. LXXXV No. 6 (MS. Ash. II 6b) contains a small sketch of a capital with the following note, written in three lines: I chorni del capitelo deono essere la quarta parte d'uno quadro (The horns of a capital must measure the fourth part of a square).

MS. S. K. M. III 72b contains two sketches of ornamentations of windows.

In MS. C. A. 308a; 938a (see Pl. LXXXII No. 1) there are several sketches of columns. One of the two columns on the right is similar to those employed by Bramante at the Canonica di S. Ambrogio. The same columns appear in the sketch underneath the plan of a castle. There they appear coupled, and in two stories one above the other. The archivolls which seem to spring out of the columns, are shaped like twisted cords, meant perhaps to be twisted branches. The walls between the columns seem to be formed out of blocks of wood, the pedestals are ornamented with a reticulated pattern. From all this we may suppose that Leonardo here had in mind either some festive decoration, or perhaps a pavilion for some hunting place or park. The sketch of columns marked "35" gives an example of columns shaped like candelabra, a form often employed at that time, particularly in Milan, and the surrounding districts for instance in the Cortile di Casa Castiglione now Silvestre, in the cathedral of Como, at Porta della Rana &c.

769.

CONCERNING ARCHITRAVES OF ONE OR SEVERAL PIECES.

An architrave of several pieces is stronger than that of one single piece, if those pieces are placed with their length in the direction of the centre of the world. This is proved because stones have their grain or fibre generated in the contrary direction i. e. in the direction of the opposite horizons of the hemisphere, and this is contrary to fibres of the plants which have ...

[Footnote: The text is incomplete in the original.]

The Proportions of the stories of a building are indicated by a sketch in MS. S. K. M. II2 11b (see Pl. LXXXV No. 15). The measures are written on the left side, as follows: br 1 1/2--6 3/4--br 1/12--2 br--9 e 1/2--1 1/2--br 5--o 9--o 3 [br=braccia; o=oncie].

Pl. LXXXV No. 13 (MS. B. 62a) and Pl. XCIII No. 1. (MS. B. 15a) give a few examples of arches supported on piers.

XIII.

Theoretical writings on Architecture.

Leonardo's original writings on the theory of Architecture have come down to us only in a fragmentary state; still, there seems to be no doubt that he himself did not complete them. It would seem that Leonardo entertained the idea of writing a large and connected book on Architecture; and it is quite evident that the materials we possess, which can be proved to have been written at different periods, were noted down with a more or less definite aim and purpose. They might all be collected under the one title: "Studies on the Strength of Materials". Among them the investigations on the subject of fissures in walls are particularly thorough, and very fully reported; these passages are also especially interesting, because Leonardo was certainly the first writer on architecture who ever treated the subject at all. Here, as in all other cases

Leonardo carefully avoids all abstract argument. His data are not derived from the principles of algebra, but from the laws of mechanics, and his method throughout is strictly experimental.

Though the conclusions drawn from his investigations may not have that precision which we are accustomed to find in Leonardo's scientific labours, their interest is not lessened. They prove at any rate his deep sagacity and wonderfully clear mind. No one perhaps, who has studied these questions since Leonardo, has combined with a scientific mind anything like the artistic delicacy of perception which gives interest and lucidity to his observations.

I do not assert that the arrangement here adopted for the passages in question is that originally intended by Leonardo; but their distribution into five groups was suggested by the titles, or headings, which Leonardo himself prefixed to most of these notes. Some of the longer sections perhaps should not, to be in strict agreement with this division, have been reproduced in their entirety in the place where they occur. But the comparatively small amount of the materials we possess will render them, even so, sufficiently intelligible to the reader; it did not therefore seem necessary or desirable to subdivide the passages merely for the sake of strict classification.

The small number of chapters given under the fifth class, treating on the centre of gravity in roof-beams, bears no proportion to the number of drawings and studies which refer to the same subject. Only a small selection of these are reproduced in this work since the majority have no explanatory text.

I.

ON FISSURES IN WALLS.

770.

First write the treatise on the causes of the giving way of walls and then, separately, treat of the remedies.

Parallel fissures constantly occur in buildings which are erected on a hill side, when the hill is composed of stratified rocks with an oblique stratification, because water and other moisture often penetrates these oblique seams carrying in greasy and slippery soil; and as the strata are not continuous down to the bottom of the valley, the rocks slide in the direction of the slope, and the motion does not cease till they have reached the bottom of the valley, carrying with them, as though in a boat, that portion of the building which is separated by them from the rest. The remedy for this is always to build thick piers under the wall which is slipping, with arches from one to another, and with a good scarp and let the piers have a firm foundation in the strata so that they may not break away from them.

In order to find the solid part of these strata, it is necessary to make a shaft at the foot of the wall of great depth through the strata; and in this shaft, on the side from which the hill slopes, smooth and flatten a space one palm wide from the top to the bottom; and after some time this smooth portion made on the side of the shaft, will show plainly which part of the hill is moving.

[Footnote: See Pl. CIV.]

771.

The cracks in walls will never be parallel unless the part of the wall that separates from the remainder does not slip down.

WHAT IS THE LAW BY WHICH BUILDINGS HAVE STABILITY.

The stability of buildings is the result of the contrary law to the two former cases. That is to say that the walls must be all built up equally, and by degrees, to equal heights all round the building, and the whole thickness at once, whatever kind of walls they may be. And although a thin wall dries more quickly than a thick one it will not necessarily give way under the added weight day by day and thus, [16] although a thin wall dries more quickly than a thick one, it will not give way under the weight which the latter may acquire from day to day. Because if double the amount of it dries in one day, one of double the thickness will dry in two days or thereabouts; thus the small addition of weight will be balanced by the smaller difference of time [18].

The adversary says that a which projects, slips down.

And here the adversary says that r slips and not c.

HOW TO PROGNOSTICATE THE CAUSES OF CRACKS IN ANY SORT OF WALL.

The part of the wall which does not slip is that in which the obliquity projects and overhangs the portion which has parted from it and slipped down.

ON THE SITUATION OF FOUNDATIONS AND IN WHAT PLACES THEY ARE A CAUSE OF RUIN.

When the crevice in the wall is wider at the top than at the bottom, it is a manifest sign, that the cause of the fissure in the wall is remote from the perpendicular line through the crevice.

[Footnote: Lines 1-5 refer to Pl. CV, No. 2. Line 9 alle due anteciedete, see on the same page.

Lines 16-18. The translation of this is doubtful, and the meaning in any case very obscure.

Lines 19-23 are on the right hand margin close to the two sketches on Pl. CII, No. 3.]

772.

OF CRACKS IN WALLS, WHICH ARE WIDE AT THE BOTTOM AND NARROW AT THE TOP AND OF THEIR CAUSES.

That wall which does not dry uniformly in an equal time, always cracks.

A wall though of equal thickness will not dry with equal quickness if it is not everywhere in contact with the same medium. Thus, if one side of a wall were in contact with a damp slope and the other were in contact with the air, then this latter side would remain of the same size as before; that side which dries in the air will shrink or diminish and the side which is kept damp will not dry. And the dry portion will break away readily from the damp portion because the damp part not shrinking in the same proportion does not cohere and follow the movement of the part which dries continuously.

OF ARCHED CRACKS, WIDE AT THE TOP, AND NARROW BELOW.

Arched cracks, wide at the top and narrow below are found in walled-up doors, which shrink more in their height than in their breadth, and in proportion as their height is greater than their width, and as the joints of the mortar are more numerous in the height than in the width.

The crack diminishes less in r o than in m n, in proportion as there is less material between r and o than between n and m.

Any crack made in a concave wall is wide below and narrow at the top; and this originates, as is here shown at b c d, in the side figure.

1. That which gets wet increases in proportion to the moisture it imbibes.

2. And a wet object shrinks, while drying, in proportion to the amount of moisture which evaporates from it.

[Footnote: The text of this passage is reproduced in facsimile on Pl. CVI to the left. L. 36-40 are written inside the sketch No. 2. L. 41-46 are partly written over the sketch No. 3 to which they refer.]

773.

OF THE CAUSES OF FISSURES IN [THE WALLS OF] PUBLIC AND PRIVATE BUILDINGS.

The walls give way in cracks, some of which are more or less vertical and others are oblique. The cracks which are in a vertical direction are caused by the joining of new walls, with old walls, whether straight or with indentations fitting on to those of the old wall; for, as these indentations cannot bear the too great weight of the wall added on to them, it is inevitable that they should break, and give way to the settling of the new wall, which will shrink one braccia in every ten, more or less, according to the greater or smaller quantity of mortar used between the stones of the masonry, and whether this mortar is more or less liquid. And observe, that the walls should always be built first and then faced with the stones intended to face them. For, if you do not proceed thus, since the wall settles more than the stone facing, the projections left on the sides of the wall must inevitably give way; because the stones used for facing the wall being larger than those over which they are laid, they will necessarily have less mortar laid between the joints, and consequently they settle less; and this cannot happen if the facing is added after the wall is dry.

a b the new wall, c the old wall, which has already settled; and the part a b settles afterwards, although a, being founded on c, the old wall, cannot possibly break, having a stable foundation on the old wall. But only the remainder b of the new wall will break away, because it is built from top to bottom of the building; and the remainder of the new wall will overhang the gap above the wall that has sunk.

774.

A new tower founded partly on old masonry.

775.

OF STONES WHICH DISJOIN THEMSELVES FROM THEIR MORTAR.

Stones laid in regular courses from bottom to top and built up with an equal quantity of mortar settle equally throughout, when the moisture that made the mortar soft evaporates.

By what is said above it is proved that the small extent of the new wall between A and n will settle but little, in proportion to the extent of the same wall between c and d. The proportion will in fact be that of the thinness of the mortar in relation to the number of courses or to the quantity of mortar laid between the stones above the different levels of the old wall.

[Footnote: See Pl. CV, No. 1. The top of the tower is wanting in this reproduction, and with it the letter n which, in the original, stands above the letter A over the top of the tower, while c stands perpendicularly over d.]

776.

This wall will break under the arch e f, because the seven whole square bricks are not sufficient to sustain the spring of the arch placed on them. And these seven bricks will give way in their middle exactly as appears in a b. The reason is, that the brick a has above it only the weight a k, whilst the last brick under the arch has above it the weight c d x a.

c d seems to press on the arch towards the abutment at the point p but the weight p o opposes resistence to it, whence the whole pressure is transmitted to the root of the arch. Therefore the foot of the arch acts like 7 6, which is more than double of x z.

II.

ON FISSURES IN NICHES.

777.

ON FISSURES IN NICHES.

An arch constructed on a semicircle and bearing weights on the two opposite thirds of its curve will give way at five points of the curve. To prove this let the weights be at n m which will break the arch a, b, f. I say that, by the foregoing, as the extremities c and a are equally pressed upon by the thrust n, it follows, by the 5th, that the arch will give way at the point which is furthest from the two forces acting on them and that is the middle e. The same is to be understood of the opposite curve, d g b; hence the weights n m must sink, but they cannot sink by the 7th, without coming closer together, and they cannot come together unless the extremities of the arch between them come closer, and if these draw together the crown of the arch must break; and thus the arch will give way in two places as was at first said &c.

I ask, given a weight at a what counteracts it in the direction n f and by what weight must the weight at f be counteracted.

778.

ON THE SHRINKING OF DAMP BODIES OF DIFFERENT THICKNESS AND WIDTH.

The window a is the cause of the crack at b; and this crack is increased by the pressure of n and m which sink or penetrate into the soil in which foundations are built more than the lighter portion at b. Besides, the old foundation under b has already settled, and this the piers n and m have not yet done. Hence the part b does not settle down perpendicularly; on the contrary, it is thrown outwards obliquely, and it cannot on the contrary be thrown inwards, because a portion like this, separated from the main wall, is larger outside than inside and the main wall, where it is broken, is of the same shape and is also larger outside than inside; therefore, if this separate portion were to fall inwards the larger would have to pass through the smaller--which is impossible. Hence it is evident that the portion of the semicircular wall when disunited from the main wall will be thrust outwards, and not inwards as the adversary says.

When a dome or a half-dome is crushed from above by an excess of weight the vault will give way, forming a crack which diminishes towards the top and is wide below, narrow on the inner side and wide outside; as is the case with the outer husk of a pomegranate, divided into many parts lengthwise; for the more it is pressed in the direction of its length, that part of the joints will open most, which is most distant from the cause of the pressure; and for that reason the arches of the vaults of any apse should never be more loaded than the arches of the principal building. Because that which weighs most, presses most on the parts below, and they sink into the foundations; but this cannot happen to lighter structures like the said apses.

[Footnote: The figure on Pl. CV, No. 4 belongs to the first paragraph of this passage, lines 1-14; fig. 5 is sketched by the side of lines l5--and following. The sketch below of a pomegranate refers to line 22. The drawing fig. 6 is, in the original, over line 37 and fig. 7 over line 54.]

Which of these two cubes will shrink the more uniformly: the cube A resting on the pavement, or the cube b suspended in the air, when both cubes are equal in weight and bulk, and of clay mixed with equal quantities of water?

The cube placed on the pavement diminishes more in height than in breadth, which the cube above, hanging in the air, cannot do. Thus it is proved. The cube shown above is better shown here below.

The final result of the two cylinders of damp clay that is a and b will be the pyramidal figures below c and d. This is proved thus: The cylinder a resting on block of stone being made of clay mixed with a great deal of water will sink by its weight, which presses on its base, and in proportion as it settles and spreads all the parts will be somewhat nearer to the base because that is charged with the whole weight.

III.

ON THE NATURE OF THE ARCH.

779.

WHAT IS AN ARCH?

The arch is nothing else than a force originated by two weaknesses, for the arch in buildings is composed of two segments of a circle, each of which being very weak in itself tends to fall; but as each opposes this tendency in the other, the two weaknesses combine to form one strength.

OF THE KIND OF PRESSURE IN ARCHES.

As the arch is a composite force it remains in equilibrium because the thrust is equal from both sides; and if one of the segments weighs more than the other the stability is lost, because the greater pressure will outweigh the lesser.

OF DISTRIBUTING THE PRESSURE ABOVE AN ARCH.

Next to giving the segments of the circle equal weight it is necessary to load them equally, or you will fall into the same defect as before.

WHERE AN ARCH BREAKS.

An arch breaks at the part which lies below half way from the centre.

SECOND RUPTURE OF THE ARCH.

If the excess of weight be placed in the middle of the arch at the point a, that weight tends to fall towards b, and the arch breaks at 2/3 of its height at c e; and g e is as many times stronger than e a, as m o goes into m n.

ON ANOTHER CAUSE OF RUIN.

The arch will likewise give way under a transversal thrust, for when the charge is not thrown directly on the foot of the arch, the arch lasts but a short time.

780.

ON THE STRENGTH OF THE ARCH.

The way to give stability to the arch is to fill the spandrils with good masonry up to the level of its summit.

ON THE LOADING OF ROUND ARCHES.

ON THE PROPER MANNER OF LOADING THE POINTED ARCH.

ON THE EVIL EFFECTS OF LOADING THE POINTED ARCH DIRECTLY ABOVE ITS

CROWN.

ON THE DAMAGE DONE TO THE POINTED ARCH BY THROWING THE PRESSURE ON

THE FLANKS.

An arch of small curve is safe in itself, but if it be heavily charged, it is necessary to strengthen the flanks well. An arch of a very large curve is weak in itself, and stronger if it be charged, and will do little harm to its abutments, and its places of giving way are o p.

[Footnote: Inside the large figure on the righi is the note: Da pesare la forza dell' archo.]

781.

ON THE REMEDY FOR EARTHQUAKES.

The arch which throws its pressure perpendicularly on the abutments will fulfil its function whatever be its direction, upside down, sideways or upright.

The arch will not break if the chord of the outer arch does not touch the inner arch. This is manifest by experience, because whenever the chord a o n of the outer arch n r a approaches the inner arch x b y the arch will be weak, and it will be weaker in

proportion as the inner arch passes beyond that chord. When an arch is loaded only on one side the thrust will press on the top of the other side and be transmitted to the spring of the arch on that side; and it will break at a point half way between its two extremes, where it is farthest from the chord.

782.

A continuous body which has been forcibly bent into an arch, thrusts in the direction of the straight line, which it tends to recover.

783.

In an arch judiciously weighted the thrust is oblique, so that the triangle c n b has no weight upon it.

784.

I here ask what weight will be needed to counterpoise and resist the tendency of each of these arches to give way?

[Footnote: The two lower sketches are taken from the MS. S. K. M. III, 10a; they have there no explanatory text.]

785.

ON THE STRENGTH OF THE ARCH IN ARCHITECTURE.

The stability of the arch built by an architect resides in the tie and in the flanks.

ON THE POSITION OF THE TIE IN THE ABOVE NAMED ARCH.

The position of the tie is of the same importance at the beginning of the arch and at the top of the perpendicular pier on which it rests. This is proved by the 2nd "of supports" which says: that part of a support has least resistance which is farthest from its solid attachment; hence, as the top of the pier is farthest from the middle of its true foundation and the same being the case at the opposite extremities of the arch which are the points farthest from the middle, which is really its [upper] attachment, we have concluded that the tie a b requires to be in such a position as that its opposite ends are between the four above-mentioned extremes.

The adversary says that this arch must be more than half a circle, and that then it will not need a tie, because then the ends will not thrust outwards but inwards, as is seen in the excess at a c, b d. To this it must be answered that this would be a very poor device, for three reasons. The first refers to the strength of the arch, since it is proved that the circular parallel being composed of two semicircles will only break where these semicircles cross each other, as is seen in the figure n m; besides this it follows that there is a wider space between the extremes of the semicircle than between the plane of the walls; the third reason is that the weight placed to counterbalance the strength of the arch diminishes in proportion as the piers of the arch are wider than the space between the piers. Fourthly in proportion as the parts at c a b d turn outwards, the piers are weaker to support the arch above them. The 5th is that all the material and weight of the arch which are in excess of the semicircle are useless and indeed mischievous; and here it is to be noted that the weight placed above the arch will be more likely to break the arch at a b, where the curve of the excess begins that is added to the semicircle, than if the pier were straight up to its junction with the semicircle [spring of the arch].

AN ARCH LOADED OVER THE CROWN WILL GIVE WAY AT THE LEFT HAND AND RIGHT HAND QUARTERS.

This is proved by the 7th of this which says: The opposite ends of the support are equally pressed upon by the weight suspended to them; hence the weight shown at f is felt at b c, that is half at each extremity; and by the third which says: in a support of equal strength [throughout] that portion will give way soonest which is farthest from its attachment; whence it follows that d being equally distant from f, e .....

If the centering of the arch does not settle as the arch settles, the mortar, as it dries, will shrink and detach itself from the bricks between which it was laid to keep them together; and as it thus leaves them disjoined the vault will remain loosely built, and the rains will soon destroy it.

786.

ON THE STRENGTH AND NATURE OF ARCHES, AND WHERE THEY ARE STRONG OR WEAK; AND THE SAME AS TO COLUMNS.

That part of the arch which is nearer to the horizontal offers least resistance to the weight placed on it.

When the triangle a z n, by settling, drives backwards the 2/3 of each 1/2 circle that is a s and in the same way z m, the reason is that a is perpendicularly over b and so likewise z is above f.

Either half of an arch, if overweighted, will break at 2/3 of its height, the point which corresponds to the perpendicular line above the middle of its bases, as is seen at a b; and this happens because the weight tends to fall past the point r.--And if, against its nature it should tend to fall towards the point s the arch n s would break precisely in its middle. If the arch n s were of a single piece of timber, if the weight placed at n should tend to fall in the line n m, the arch would break in the middle of the arch e m, otherwise it will break at one third from the top at the point a because from a to n the arch is nearer to the horizontal than from a to o and from o to s, in proportion as p t is greater than t n, a o will be stronger than a n and likewise in proportion as s o is stronger than o a, r p will be greater than p t.

The arch which is doubled to four times of its thickness will bear four times the weight that the single arch could carry, and more in proportion as the diameter of its thickness goes a smaller number of times into its length. That is to say that if the thickness of the single arch goes ten times into its length, the thickness of the doubled arch will go five times into its length. Hence as the thickness of the double arch goes only half as many times into its length as that of the single arch does, it is reasonable that it should carry half as much more weight as it would have to carry if it were in direct proportion to the single arch. Hence as this double arch has 4 times the thickness of the single arch, it would seem that it ought to bear 4 times the weight; but by the above rule it is shown that it will bear exactly 8 times as much.

THAT PIER, WHICH is CHARGED MOST UNEQUALLY, WILL SOONEST GIVE WAY.

The column c b, being charged with an equal weight, [on each side] will be most durable, and the other two outward columns require on the part outside of their centre as much pressure as there is inside of their centre, that is, from the centre of the column, towards the middle of the arch.

Arches which depend on chains for their support will not be very durable.

THAT ARCH WILL BE OF LONGER DURATION WHICH HAS A GOOD ABUTMENT OPPOSED TO ITS THRUST.

The arch itself tends to fall. If the arch be 30 braccia and the interval between the walls which carry it be 20, we know that 30 cannot pass through the 20 unless 20 becomes likewise 30. Hence the arch being crushed by the excess of weight, and the walls offering insufficient resistance, part, and afford room between them, for the fall of the arch.

But if you do not wish to strengthen the arch with an iron tie you must give it such abutments as can resist the thrust; and you can do this thus: fill up the spandrels m n with stones, and direct the lines of the joints between them to the centre of the circle of the arch, and the reason why this makes the arch durable is this. We know very well that if the arch is loaded with an excess of weight above its quarter as a b, the wall f g will be thrust outwards because the arch would yield in that direction; if the other quarter b c were loaded, the wall f g would be thrust inwards, if it were not for the line of stones x y which resists this.

787.

PLAN.

Here it is shown how the arches made in the side of the octagon thrust the piers of the angles outwards, as is shown by the line h c and by the line t d which thrust out the pier m; that is they tend to force it away from the centre of such an octagon.

788.

An Experiment to show that a weight placed on an arch does not discharge itself entirely on its columns; on the contrary the greater the weight placed on the arches, the less the arch transmits the weight to the columns. The experiment is the following. Let a man be placed on a steel yard in the middle of the shaft of a well, then let him spread out his hands and feet between the walls of the well, and you will see him weigh much less on the steel yard; give him a weight on the shoulders, you will see by experiment, that the greater the weight you give him the greater effort he will make in spreading his arms and legs, and in pressing against the wall and the less weight will be thrown on the steel yard.

IV.

ON FOUNDATIONS, THE NATURE OF THE GROUND AND SUPPORTS.

789.

The first and most important thing is stability.

As to the foundations of the component parts of temples and other public buildings, the depths of the foundations must bear the same proportions to each other as the weight of material which is to be placed upon them.

Every part of the depth of earth in a given space is composed of layers, and each layer is composed of heavier or lighter materials, the lowest being the heaviest. And this can be proved, because these layers have been formed by the sediment from water carried down to the sea, by the current of rivers which flow into it. The heaviest part of this sediment was that which was first thrown down, and so on by degrees; and this is the action of water when it becomes stagnant, having first brought down the mud whence it first flowed. And such layers of soil are seen in the banks of rivers, where their constant flow has cut through them and divided one slope from the other to a great depth; where in gravelly strata the waters have run off, the materials have, in consequence, dried and been converted into hard stone, and this happened most in what was the finest mud; whence we conclude that every portion of the surface of the earth was once at the centre of the earth, and viceversa &c.

790.

The heaviest part of the foundations of buildings settles most, and leaves the lighter part above it separated from it.

And the soil which is most pressed, if it be porous yields most.

You should always make the foundations project equally beyond the weight of the walls and piers, as shown at m a b. If you do as many do, that is to say if you make a foundation of equal width from the bottom up to the surface of the ground, and charge it above with unequal weights, as shown at b e and at e o, at the part of the foundation at b e, the pier of the angle will weigh most and thrust its foundation downwards, which the wall at e o will not do; since it does not cover the whole of its foundation, and therefore thrusts less heavily and settles less. Hence, the pier b e in settling cracks and parts from the wall e o. This may be seen in most buildings which are cracked round the piers.

791.

The window a is well placed under the window c, and the window b is badly placed under the pier d, because this latter is without support and foundation; mind therefore never to make a break under the piers between the windows.

792.

OF THE SUPPORTS.

A pillar of which the thickness is increased will gain more than its due strength, in direct proportion to what its loses in relative height.

EXAMPLE.

If a pillar should be nine times as high as it is broad--that is to say, if it is one braccio thick, according to rule it should be nine braccia high--then, if you place 100 such pillars together in a mass this will be ten braccia broad and 9 high; and if the first pillar could carry 10000 pounds the second being only about as high as it is wide, and thus lacking 8 parts of its proper length, it, that is to say, each pillar thus united, will bear eight times more than when disconnected; that is to say, that if at first it would carry ten thousand pounds, it would now carry 90 thousand.

V.

ON THE RESISTANCE OF BEAMS.

793.

That angle will offer the greatest resistance which is most acute, and the most obtuse will be the weakest.

[Footnote: The three smaller sketches accompany the text in the original, but the larger one is not directly connected with it. It is to be found on fol. 89a of the same Manuscript and there we read in a note, written underneath, coverchio della perdicha del castello (roof of the flagstaff of the castle),--Compare also Pl. XCIII, No. 1.]

794.

If the beams and the weight o are 100 pounds, how much weight will be wanted at ae to resist such a weight, that it may not fall down?

795.

ON THE LENGTH OF BEAMS.

That beam which is more than 20 times as long as its greatest thickness will be of brief duration and will break in half; and remember, that the part built into the wall should be steeped in hot pitch and filleted with oak boards likewise so steeped. Each beam must pass through its walls and be secured beyond the walls with sufficient chaining, because in consequence of earthquakes the beams are often seen to come out of the walls and bring down the walls and floors; whilst if they are chained they will hold the walls strongly together and the walls will hold the floors. Again I remind you never to put plaster over timber. Since by expansion and shrinking of the timber produced by damp and dryness such floors often crack, and once cracked their divisions gradually produce dust and an ugly effect. Again remember not to lay a floor on beams supported on arches; for, in time the floor which is made on beams settles somewhat in the middle while that part of the floor which rests on the arches remains in its place; hence, floors laid over two kinds of supports look, in time, as if they were made in hills [Footnote: 19 M. RAVAISSON, in his edition of MS. A gives a very different rendering of this passage translating it thus: Les planchers qui sont soutenus par deux differentes natures de supports paraissent avec le temps faits en voute a cholli.]

Remarks on the style of Leonardo's architecture.

A few remarks may here be added on the style of Leonardo's architectural studies. However incomplete, however small in scale, they allow us to establish a certain number of facts and probabilities, well worthy of consideration.

When Leonardo began his studies the great name of Brunellesco was still the inspiration of all Florence, and we cannot doubt that Leonardo was open to it, since we find among his sketches the plan of the church of Santo Spirito[Footnote 1: See Pl. XCIV, No. 2. Then only in course of erection after the designs of Brunellesco, though he was already dead; finished in 1481.] and a lateral view of San Lorenzo (Pl. XCIV No. 1), a plan almost identical with the chapel Degli Angeli, only begun by him (Pl. XCIV, No. 3) while among Leonardo's designs for domes several clearly betray the influence of Brunellesco's Cupola and the lantern of Santa Maria del Fiore[Footnote 2: A small sketch of the tower of the Palazzo della Signoria (MS. C.A. 309) proves that he also studied mediaeval monuments.]

The beginning of the second period of modern Italian architecture falls during the first twenty years of Leonardo's life. However the new impetus given by Leon Battista Alberti either was not generally understood by his contemporaries, or those who appreciated it, had no opportunity of showing that they did so. It was only when taken up by Bramante and developed by him to the highest rank of modern architecture that this new influence was generally felt. Now the peculiar feature of Leonardo's sketches is that, like the works of

Bramante, they appear to be the development and continuation of Alberti's.

But a question here occurs which is difficult to answer. Did Leonardo, till he quitted Florence, follow the direction given by the dominant school of Brunellesco, which would then have given rise to his "First manner", or had he, even before he left Florence, felt Alberti's influence--either through his works (Palazzo Ruccellai, and the front of Santa Maria Novella) or through personal intercourse? Or was it not till he went to Milan that Alberti's work began to impress him through Bramante, who probably had known Alberti at Mantua about 1470 and who not only carried out Alberti's views and ideas, but, by his designs for St. Peter's at Rome, proved himself the greatest of modern architects. When Leonardo went to Milan Bramante had already been living there for many years. One of his earliest works in Milan was the church of Santa Maria presso San Satiro, Via del Falcone[Footnote 1: Evidence of this I intend to give later on in a Life of Bramante, which I have in preparation.].

Now we find among Leonardos studies of Cupolas on Plates LXXXIV and LXXXV and in Pl. LXXX several sketches which seem to me to have been suggested by Bramante's dome of this church.

The MSS. B and Ash. II contain the plans of S. Sepolcro, the pavilion in the garden of the duke of Milan, and two churches, evidently inspired by the church of San Lorenzo at Milan.

MS. B. contains besides two notes relating to Pavia, one of them a design for the sacristy of the Cathedral at Pavia, which cannot be supposed to be dated later than 1492, and it has probably some relation to Leonardo's call to Pavia June 21, 1490[Footnote 2: The sketch of the plan of Brunellesco's church of Santo Spirito at Florence, which occurs in the same Manuscript, may have been done from memory.]. These and other considerations justify us in concluding, that Leonardo made his studies of cupolas at Milan, probably between the years 1487 and 1492 in anticipation of the erection of one of the grandest churches of Italy, the Cathedral of Pavia. This may explain the decidedly Lombardo-Bramantesque tendency in the style of these studies, among which only a few remind us of the forms of the cupolas of S. Maria del Fiore and of the Baptistery of Florence. Thus, although when compared with Bramante's work, several of these sketches plainly reveal that master's influence, we find, among the sketches of domes, some, which show already Bramante's classic style, of which the Tempietto of San Pietro in Montorio, his first building executed at Rome, is the foremost example[Footnote 3: It may be mentioned here, that in 1494 Bramante made a similar design for the lantern of the Cupola of the Church of Santa Maria delle Grazie.].

On Plate LXXXIV is a sketch of the plan of a similar circular building; and the Mausoleum on Pl. XCVIII, no less than one of the pedestals for the statue of Francesco Sforza (Pl. LXV), is of the same type.

The drawings Pl. LXXXIV No. 2, Pl. LXXXVI No. 1 and 2 and the ground flour ("flour" sic but should be "floor" ?) of the building in the drawing Pl. XCI No. 2, with the interesting decoration by gigantic statues in large niches, are also, I believe, more in the style Bramante adopted at Rome, than in the Lombard style. Are we to conclude from this that Leonardo on his part influenced Bramante in the sense of simplifying his style and rendering it more congenial to antique art? The answer to this important question seems at first difficult to give, for we are here in presence of Bramante, the greatest of modern architects, and with Leonardo, the man comparable with no other. We have no knowledge of any buildings erected by Leonardo, and unless we admit personal intercourse--which seems probable, but of which there is no proof--, it would be difficult to understand how Leonardo could have affected Bramante's style. The converse is more easily to be admitted, since Bramante, as we have proved elsewhere, drew and built simultaneously in different manners, and though in Lombardy there is no building by him in his classic style, the use of brick for building, in that part of Italy, may easily account for it.

Bramante's name is incidentally mentioned in Leonardo's manuscripts in two passages (Nos. 1414 and 1448). On each occasion it is only a slight passing allusion, and the nature of the context gives us no due information as to any close connection between the two artists.

It might be supposed, on the ground of Leonardo's relations with the East given in sections XVII and XXI of this volume, that some evidence of oriental influence might be detected in his architectural drawings. I do not however think that any such traces can be pointed out with certainty unless perhaps the drawing for a Mausoleum, Pl. XC VIII.

Among several studies for the construction of cupolas above a Greek cross there are some in which the forms are decidedly monotonous. These, it is clear, were not designed as models of taste; they must be regarded as the results of certain investigations into the laws of proportion, harmony and contrast.

The designs for churches, on the plan of a Latin cross are evidently intended to depart as little as possible from the form of a Greek cross; and they also show a preference for a nave surrounded with outer porticos.

The architectural forms preferred by Leonardo are pilasters coupled (Pl. LXXXII No. 1; or grouped (Pl. LXXX No. 5 and XCIV No. 4), often combined with niches. We often meet with orders superposed, one in each story, or two small orders on one story, in combination with one great order (Pl. XCVI No. 2).

The drum (tamburo) of these cupolas is generally octagonal, as in